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Bacon	Irradiated Food(s)	Consumers
Irradiation	Cost Analysis	Energy Savings
Sterilization	Consumer Acceptance	
Meat	Acceptability	

$0.08/lb
$0.07/lb
$0.03/lb

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This paper is about costs and energy savings obtained by irradiating bacon. Sterilized by irradiation (25 kGy), bacon without added nitrite does not contain nitrosamines and does not constitute botulism hazard. If bacon is irradiation-sterilized while refrigerated, the cost of irradiation is about ~~0.8¢/lb~~; if irradiation-sterilized while frozen, the costs of irradiation and freezing would be about ~~3¢/lb~~. Substerilizing irradiation doses of 7.5 to 15 kGy would give about 80 days extension of bacon stored and distributed refrigerated. The irradiation costs, in this case, would be about ~~0.7¢/lb~~.

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PREFACE

Reducing or eliminating nitrites in bacon would reduce or eliminate the formation of highly carcinogenic nitrosamines, but would increase the threat of botulism. Sterilized by irradiation, bacon without nitrite does not contain nitrosamines and does not cause botulism. Consumer panel taste tests show no difference in acceptance between bacon with the usual cure of 120 ppm of nitrite and the irradiated bacon without any nitrite. The question has been asked, "What are the costs, and what are the energy savings of irradiating the bacon?".

The present paper answers these questions.

DoD Food Program Requirement USA 5-1.

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COST OF IRRADIATING BACON AND THE ASSOCIATED ENERGY SAVINGS

INTRODUCTION

Sterilized by irradiation, bacon without nitrite does not contain nitrosamines and does not cause botulism. Consumer panel taste tests show no difference in acceptance between bacon with the usual cure of 120 ppm of nitrite and the irradiated bacon without any nitrite. Expert panels, however, note a difference reflecting the lack of nitrite. When only 20 ppm nitrite is used for curing the bacon to be irradiated, even expert panels do not taste the difference between that and the fully cured product. No nitrosamines nor a greatly reduced amount of nitrosamines (less than 2 ppb nitrosopyrrolidene) is detected in this low nitrite (20 ppm) irradiated bacon. No nitrosamines are detected in the irradiated bacon without any nitrite added.

Extensive wholesomeness tests on irradiated bacon, as well as many other irradiated meats, have been done during the last 30 years. To date, these tests have failed to detect any harmful effects in experimental animals eating irradiated meats, and short-term studies on human volunteers have also failed to detect any effect of irradiated meats different from that of unirradiated meats. In 1963, FDA and USDA cleared irradiated bacon. In 1968, the FDA revoked the approvals because re-evaluation of the wholesomeness data found them to be inadequate for support of the petition. Since 1968, international wholesomeness studies on a broad spectrum of irradiated foods have not been able to detect any harmful effects of consuming irradiated foods.

For the sake of clarity, we will limit the discussion to bacon. Reducing or eliminating nitrite in bacon would reduce or eliminate the formation of highly carcinogenic nitrosamines, but, if the bacon is not sterilized, would increase the threat of botulism.

COST SAVINGS OF IRRADIATED BACON

Cost of producing irradiated meats can be estimated fairly accurately. The overall benefits, on the other hand, include intangibles difficult to assess in monetary values. One of the best studies made was a cost-benefits analysis of irradiated meats by Department of Commerce, which showed that the military could have saved a significant amount of money if irradiated bacon had been available. Out of 10.5 million pounds of bacon procured in FY68 for Vietnam, the savings would have been \$3.463 million if irradiated bacon had been used in place of frozen raw bacon and \$7.131 million if used in place of prefried bacon.

Many factors not readily equated with monetary values were excluded in the analyses. These factors relate to absolute greater microbial safety, absolute guarantee from trichina, more flexibility in storage and transportation, and savings in energy, and are usually in favor of irradiated foods.

IRRADIATION COSTS

In what follows, typical irradiation costs will be calculated. These calculations do not consider reduced distribution costs, reduced energy costs, and reduced losses caused by improper storage condition (e.g., failure of refrigeration facilities and over-extended storage time because of less than expected sales).

Size of the Plant. Many US bacon packers have an annual production in the 30-150 million pounds range. In the following, we will consider, therefore, a plant with an annual production of 100 million pounds.

Sterilizing Dose (D). We will assume a sterilizing dose of 25 kGy (= 25 kilogray = 25 kilojoule of radiation energy absorbed per kilogram of the food), i.e., 2.5 megarad. (Different estimates based on experimental measurements have shown that a dose in the range of 19-25 kGy reduces the number of *C. botulinum* spores to 10^{-12} of the initial value.) Substerilizing doses (e.g., 7.5 kGy) could be used, and would extend the shelf-life of bacon to 80 days if it is stored refrigerated and packaged in conventional commercial retail packages. Lowering the dose from 25 kGy to 7.5 kGy does not, however, affect the irradiation cost per pound of bacon very much.

Plant utilization (n_1). Bacon production is fairly uniform during the year. An average of 6000 hrs of operation per year will therefore be assumed.

Radiation Utilization (n_2). In practical application, only about 30-50% of the radiation is absorbed in the food; the rest will be absorbed in the source, source frame, and conveyor, and will escape between the packages and boxes, impinging on the walls. Consequently, we will use the conservative value of 30%.

Size of the Source (W). The source size required depends on the amount of product that must be irradiated per hour, the dose, and the irradiation utilization factor.

We have generally that

$$W = \frac{1}{8000} \cdot \frac{X \cdot D}{n_2}$$

where

W = source strength in kwatt

X = lb of product irradiated per hour = $10^8/n_1 = 10^8/6 \cdot 10^3$
$= 1.7 \cdot 10^4$ lb/hour

D = dose in kGy = 25 kGy for bacon

n_2 = radiation utilization factor of 0.3

1/8000 = is a conversion factor for the units

Therefore, in the present case, we have

$$W = \frac{1}{8000} \cdot \frac{17000 \times 25}{0.3} = 177 \text{ kW}.$$

The 177 kW plant is larger than those currently used by the medical industry, but the plastic curing industry has plants with hundreds of kilowatts. If other cured products such as ham and sausages are also irradiated, the source would be larger. For a source, we could use a Co-60 or Cs-137 isotope source (gamma ray emitters), or we could use a 4- to 10-MeV electron accelerator. In case of bacon, a 4-MeV accelerator could do the job. These machines are currently available in 30- to 250-kwatt range.

Irradiation Plant Cost. A complete 200-kwatt Co-60 irradiation plant would cost about $10,150,000 if the price of Co-60 is about 60¢ per curie. The Cs-137 plant would cost about the same if the Cs-137 price is 13¢ per curie. A 10-MeV, 200-kW linear accelerator plant would cost about $2.45 million. A 4-MeV, 200-kW accelerator plant would cost about $1.8 million. The 4-MeV accelerator could irradiate 1/2" of product from one side quite uniformly. The irradiation efficiency could be as high as 56% if the product is uniformly packed at 1/2" thickness on the conveyor. Usually, product thickness varies and there will be spacing between the packages, reducing the efficiency to about 40%. The assumed efficiency of n_2 = 30% in Eq. (1) is quite conservative and easily obtainable.

Annual Operational Costs. The annual operating cost for the Co-60 facility is about $1.165 million, including the cost for replenishing the source. For the Cs-137 facility, the operational costs are about $350,000; they are much less than for Co-60 because the Cs-137 has a longer half-life. The annual 6000-hour operational costs for a 10-MeV, 200-kW linear accelerator are about $425,000. The annual 6000-hour operational costs for a 4-MeV electron accelerator are about $400,000.

The Irradiation Costs per Pound of Bacon. The 5-year straight-line depreciation of the initial capital outlay distributed on each pound of bacon product and the operational irradiation costs are shown in the following table.

TABLE 1 - Cost of Irradiation-Sterilizing Bacon*

Source	5-Year Plant Depreciation Costs in ¢ per lb	Operational Costs in ¢ per lb	Total Cost in ¢ per lb
Co-60 isotope	2.03	1.2	3.23
Cs-137 isotope	2.03	0.32	2.38
10-MeV accelerator	0.49	0.43	0.92
4-MeV accelerator	0.36	0.40	0.76

*Plant Size: 100,000,000 lb per year.

The 4-MeV, 200-kW accelerator can be considered an "off-the-shelf item". The technology for the 10-MeV, 200-kW accelerator is on the drawing board. The components are available, but so far the industry has not purchased one. The Cs-137 is still "buried" in the ground as waste from nuclear reactors. Large isotope separation plants would have to be built (with about a 3-year lead time), and the large-scale application might well lower the price very much below the price of 13¢ per curie quoted above. The Co-60 could be produced in power reactors with a two-year lead-time. Large-scale application would most likely lower the price from 60¢ to 30¢ a curie.

Cost of Freezing. Low-dose irradiation for refrigerated storage and distribution of bacon can be done at conventional refrigeration temperatures. For shelf-stable bacon, irradiated with a sterilizing dose, the highest quality is obtained when it is irradiated in frozen state of -30°C. The cost of freezing the bacon is about 2¢/lb (the costs of freezing bacon are significantly lower than for other meat products because of the higher fat content in bacon). Therefore, the total cost of irradiation sterilizing the bacon in frozen state using a 4-MeV accelerator would be less than 3¢/lb (0.76 + 2¢/lb).

Other Cost Factors. The irradiation-sterilized bacon, vacuum-packed in hermetically sealed containers, can be distributed at room temperature. Significant savings would then result from reduced distribution and storage costs. Fewer, but larger, shipments to stores could be made. Market fluctuations would be of less concern. The corresponding savings vary greatly and are therefore difficult to quantify in monetary values, but are likely to do more than compensate for the irradiation costs. If storage is planned for 80 days or more, the radiation-sterilized bacon will require, however, special oxygen-tight packaging. The low-dose irradiated bacon, packed in conventional, transparent, vacuum-sealed plastic pouches, will be distributed under conventional refrigeration, the present distribution practice. Low-dose irradiation will be applied to refrigerated bacon after packaging, on the way to a storehouse or to a shipping truck at a cost of less than 0.7¢/lb.

The Energy Savings. In Table 2, we compare the energy requirements for processing, distribution, and home storage and preparation of frozen vs. irradiated bacon.

TABLE 2 - Savings in Energy if Irradiation-Sterilized Bacon is Used

Energy Used in Btu/lb of Bacon	Frozen Bacon Btu/lb	Irradiated Bacon Btu/lb
From slaughter to curing	465	465
Smokehouse	345	345
Packaging into plastic-aluminum laminate	1600	1600
Blast freezing bacon	2150	2150
Cooling during irradiation	0	130
Irradiation	0	70
Carton boxes for shipping	1030	1030
Cooling during storage 3-1/2 weeks	2200	0
Shipping	260	260
Freezing during shipment	130	0
Retail market refrigeration	260	0
Home refrigeration	3400	0
Home preparation	860	860
	12,700	6910

The energy savings from using irradiated products would be about 45%.